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No. 607

THE AERODYNAMIC WIND VANE AND THE INHERENT STABILITY OF AIRPLANES

By A. Lapresle

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The design of the device described below rests on a fundamental consideration which it may be interesting to recall. Inherent-stability investigations are based, in principle, on the following line of reasoning.

An airplane, originally in equilibrium about its C.G. is assumed to be deflected from this position through an angle Δi, the variation Δi being so sudden that the path of the C.G. and the airplane speed do not change while it is taking place. The aerodynamic forces acting on the wings, tail surfaces, fuselage, etc., which, as a whole, exerted a zero moment ($M_G = 0$) about the center of gravity at the instant of equilibrium, now exert a moment $M_G \neq 0$.

V being constant and the path of the C.G. being unchanged according to our assumption, M may be considered, for the present investigation, as a function of i alone: $M_G = f\ (i)$, Hence, for the variation Δi, we can write

$$\Delta M_G = f'\ (i)\ \Delta i.$$

*"Giroutte Aérodynamique et Stabilité de Forme des Planeurs." From Bulletin Technique of the Services Techniques de L'Aéronautique, No. 66, February, 1930, pp. 6-17.

There is inherent or static stability, when the direction of ΔM_G is such that this elementary moment tends to produce a rotation opposite to Δi. If, on the contrary, ΔM_G tends to increase the deflection Δi, there is inherent or static instability. In the particular case when ΔM_G equals zero, there is neutral equilibrium.

Giving ΔM_G and Δi positive or negative signs according to their direction, the above rule is expressed by the following algebraic ratio:

$$\frac{\Delta M_G}{\Delta i} = f'(i).$$

There is stability or instability according to the positive or negative sign of this ratio. For experimental-stability investigations, a method should be devised for accurately determining the direction of the derivative

$$\frac{\Delta M_G}{\Delta i} = f'(i),$$

or of the slope of the successive tangents to the curve of the moments about the C.G. This is not always possible with current balance-test methods, since the measured moments usually refer to axes very remote from the C.G., such as the leading edge of the wings, for example. It is then necessary to subtract from these moments a calculated moment of the same order of magnitude from which the resultant moment about the C.G. is finally derived. A physical quantity, however, is never accurately defined when it is a difference between two other

practically equivalent quantities. Wrong conclusions are therefore liable to be drawn from certain tests, especially when the derivative $\frac{\Delta M_G}{\Delta i}$ approaches zero, which frequently occurs under certain conditions of flight, even with well-designed airplanes. Besides, since the inherent stability of such airplanes is always small enough to insure good maneuverability, it is necessary to reject, in the investigation of this stability, all approximate methods such as those based on the fact that the moments about the leading edge vary linearly in terms of C_z, which is often incorrect under certain conditions involving the limited dive or stall. All these troubles are remedied by the wind vane described below, which indicates the moments about the C.G. directly and without calculation, leaving no doubt as to the sign of $\frac{\Delta M_G}{\Delta i}$.

Description of Wind Vane

Pitching moments.- For pitching-moment investigations the model is mounted as a wind vane (Fig. 1), the lateral inertia axis of the airplane which passes through its C.G., marked on the model, being taken as the pivoting axis AB*. When the

*This wind-vane arrangement has long been used for the direct determination of the center of lift of airfoils. It was described in Eiffel's work on the experiments of the Champ de Mars and Auteuil laboratories. According to the ideas which prevailed at that time, there was stability when the center of lift moved toward the front of the airplane with decreasing angle of attack. It was then thought that the resultant, in moving forward, would level off the airplane. A displacement of the center of lift in the opposite direction would likewise indicate instability. (Continued at bottom of next page.)

model tends toward a certain position of equilibrium, it moves the lower supporting spindle B and causes it to pivot about its own axis. An incidence-recording dial, 50 cm (about 20 inches) in diameter, is clamped on this spindle, preferably outside of the air stream. Hence this dial makes the same angular motions as the model. Moreover, (and this is the chief innovation of the system), a tightly fitting square transverse bar (a b) is mounted on the spindle B. This bar carries a small plate P, normal to the wind and capable of sliding along a b.

The plate P being fixed at a given distance from the axis, the airplane-plate system is installed in a position of equilibrium in the air stream, practically independent of the test velocity. In this position the aerodynamic moment about the axis B evidently balances the moment of the plate, which generally assumes a position inclined to the wind. Since, how-

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(Continued from footnote on page 3)

This method is correct, but gives only a qualitative idea of stability, since it shows only the direction but not the magnitude of the restoring moments. This method can be supplemented by plotting the sheaf of resultants with the aid of the polar, but the plotting takes much time and the result finally obtained by several successive operations does not have the desirable degree of accuracy.

Since then, the same line of reasoning was frequently adopted for the determination of the position β of a point of the resultant with respect to the leading edge by using a quick method which consists in deducing it from the coefficient of the moment C_m about the leading edge and from the corresponding lift coefficient C_z by

$$\beta = \frac{C_m}{C_z}.$$

In practice this approximate relation holds good only when the moment of the drag component C_x is small as compared with that of the C_z component. This relation does not hold good in diving and at large angles of attack. These cases of airplane flight are very important. Owing to the possible errors of this approximate method, it should be absolutely discarded in the investigation of these particular cases.

ever, the spindle a b is mounted with a tight fit on the axis B, it is brought back to a position practically normal to the wind, while holding the calibrated plate by hand. The airplane keeps very close to its original angle of attack, because the aerodynamic moment of the plate varies very little when the plate is deflected $\pm 20^\circ$ from its normal position. The aerodynamic moment of the airplane is found by a preliminary calibration to be equal and opposite to this moment.

A series of antagonistic moments is created by shifting the plate toward or from the axis. The elements of the curve of the aerodynamic moments about the C.G. are thus directly obtained in terms of the angle of attack. Besides, a whole set of plates of different sizes is available, so that moments covering a very wide range can be produced.

Positions of stable equilibrium are studied without difficulty. For unstable positions the incidence of the system is changed by the operator, who adjusts the incidence-indicating plate by hand. When a position of unstable equilibrium is reached, the slightest deviation to the right or left tends to increase automatically. The operator can determine by touch the position in which the plate tends to move away from him first in one direction and then in the other. He then knows that a position of unstable equilibrium has been reached and is able to determine it with a fair degree of precision. The angles of the calibrated plate are usually read to within 0.25 or 0.5°.

For calibration, the plate is fixed in different positions along the spindle a b. No airplane being mounted on the spindle, the aerodynamic moment is balanced by weights acting over pulleys on a wire, the other end of which is attached to a given point of the incidence plate. This calibration shows that the plate reaches a state of practically neutral equilibrium, when it is normal to the wind. This point is important since it shows that, in the above method, a practically neutral moment is opposed to the moment of the airplane. The cases of unstable equilibrium are therefore actually due to the airplane and not to the plate.

The whole system, consisting of spindles A and B, the model, the calibrated plate, etc., is mounted on a rectangular frame, the pivots O_1 O_2 of which rest on a supporting structure. Thus the pivoting axis AB can be inclined to the wind and the conditions of fore-and-aft stability can be investigated when the plane of symmetry of the airplane is set at a certain angle of side slip with respect to the relative wind. For the latter tests a spindle, which balances the models with respect to gravity, is provided above the calibrated plate. This spindle can be set at any inclination and carries suitable sliding weights.

Plate P is kept normal to the wind by rotating the square rod a b in its supporting clamp through the proper angle after loosening the set screw. The weight of this plate is balanced

by an equivalent mass, of small aerodynamic moment, mounted symmetrically with respect to the B axis (Fig. 3). Arrangements of the model for the various longitudinal stability tests are shown in Figures 2 and 3. In Figure 2 the model has the position of normal rectilinear flight with respect to the wind, and in Figure 3 it has a certain angle of side slip.

The hinge moments are measured in the same way as the pitching moments, the stabilizer-elevator assembly being mounted in such a manner that the pivoting axis AB and the elevator hinge coincide, the stabilizer having an independent support. Such an installation (developed jointly with Mr. Bouchenot and the S.E.C.M.) is shown in Figure 4.

Yawing Moments

The installation of a model for the measurement of the yawing moments, which affect directional stability, is shown diagrammatically in Figure 5. It comprises the normal plate arrangement which produces an antagonistic moment balancing the aerodynamic moment produced by angular deflections of the model about the normal axis. By rotating the frame about the pivots O_1 O_2 the airplane can be set at a given angle of attack, leaving it still possible to measure the moments about an axis fixed with respect to the model.

The attachment fitting also enables the measurement of the aerodynamic moments with respect to the vertical axis normal to

the wind. In this case the frame is not inclined about O_1 O_2, only the model being pivoted about its own support. Figures 6 and 7 show the installation during a test. In Figure 6 the model has only a small angle of attack, while in Figure 7, it has a large one.

Rolling Moments

A device for the direct measurement of the rolling moments was added to the wind vane. Unlike the apparatus already mentioned, this device cannot indicate the stability of the airplane about its longitudinal axis. A model oscillating freely about an axis parallel to the wind has a constant angle of attack, whatever may be its angle of roll. No static stabilizing moment of aerodynamic origin can develop as a result of turning the model to the right or to the left.

Hence, it is not by opposing a neutral moment, from the viewpoint of stability, to the rolling moment (which may result from the joint operation of the ailerons) that the model can be stopped at a given angle of roll indicating the magnitude of this rolling moment. In this case a stable moment must necessarily be opposed to the rolling moment.

After trying several more or less successful devices, one of which had been developed by Mr. Bouchenot and the S.E.C.M., we finally completed, in cooperation with the S.P.C.A., the device shown in Figure 8. Mr. Rebuffet, an engineer of the S.R.Aé., is now putting the finishing touches to this device in

the small wind tunnel at Issy-les-Moulineaux.

This device consists chiefly of a strong spindle AB mounted on ball bearings and carrying at its front end a vertical rod a b. The upper end of this rod is provided with an adjustable incidence plate to which the bottom of the fuselage of the model is secured. Two unequal sliding weights P and p can be stopped at any point on this rod. When the model is inclined through an angle θ to the right or to the left, the weight P balances the weight of the airplane on the axis AB, and the weight p balances the aerodynamic moment which it is proposed to measure. The angle of roll θ is directly recorded on the dial c, the needle of which is controlled by a set of bevel gears.

The rolling moments can be measured in many different ways, a few of which are described below:

a) A variation of the angle of attack of the model can be effected by varying the inclination of the supporting plate to which the fuselage is attached. In this case the moments are measured about an axis which remains parallel to the wind.

b) The angle of attack can also be varied by inclining the spindle AB about an axis O. This spindle is held in place by means of a circular sector m n, with a center O, which is tightly secured by a clamp d carried by the support of the whole system. In this case the moments are measured about an axis which is fixed with respect to the airplane.

c) In positions of drift the airplane can be set at an

angle of side slip by rotating the supporting rod a b about its own axis. The moments are then measured about an axis parallel to the direction of the air flow.

d) Moreover, the whole supporting frame can be rotated about an axis CD and the moments measured about an axis fixed with respect to the airplane.

e) By combining all these operations the airplane can be easily set simultaneously at any angle of attack and at any angle of side slip, the moments being measured either with respect to an axis parallel to the air flow or with respect to an axis fixed with reference to the airplane.

f) For the purpose of measuring the rolling moment due, for example, to a deflection of the rudder, the airplane can be mounted on the end of the spindle AB, in such a manner that the axis of the latter passes through the C.G., or the arrangement of Figure 8 can be preserved, the moment being then determined for two different positions of the airplane above the AB axis. From the two known moments with respect to two parallel axes, the moment with respect to any other parallel axis or the magnitude of the lateral rudder force which produces the rolling moment can be easily determined.

The difficulty lies in the calibration of the moment of the weight p, in such cases as b, in which the airplane assumes an angle of roll about the axis AB, which is itself inclined to the wind. The following solution was developed during the finishing tests.

The axis AB (Fig. 9) is inclined (with no wind) at an angle α to the horizontal and an airplane model is installed in neutral equilibrium about AB by means of the rod a b, and the counterweight P. An additional weight p is then placed at a certain distance h from the axis AB, and another balanced rod e f, carrying a movable counterweight Q, is clamped tightly in the sleeve f.

It is now proposed to determine the moment of p with respect to AB for an inclination θ of the rod a b with respect to the vertical plane containing AB. The weight Q is moved along e f until the inclination of the rod a b is about θ. At this instant the rod e f can be restored to the horizontal position by rotating the sleeve f, and the inclination θ_1 of a b is noted for this position of e f. Then let l represent the distance between the weight Q and the axis. The moment of P which corresponds simultaneously to the inclination θ_1 and to the angle of attack α is evidently

$$Q\, l \cos \alpha$$

The system can be thus calibrated once for all for different values of h, of the inclination or angle of roll θ and of the angle of attack α. In practice the sensitivity is increased during tests in the air stream by varying h so as to keep θ in the neighborhood of 45°.

The device has not yet given practical results, as it is only now nearing completion. It has been mentioned simply to

call attention to its existence.

Devices for Mounting the Models

The fittings for attaching the models to the measuring devices may greatly affect the aerodynamic phenomena. They should therefore be so designed as to cause the least possible disturbance of the fluid, especially in the neighborhood of the auxiliary and control surfaces under investigation. These requirements are believed to be filled by all our attachment fittings, as will be shown later. Thus, for longitudinal stability investigations, the attachment fittings and supports are located laterally far from the tail surfaces. For directional stability, the combined attachment fittings do not affect the rudder and ailerons, while, for the rolling moments, the supporting structure does not in any way interfere with the fluid flow about the ailerons and the rudder. In short, these different fittings reduce to a minimum the effect of mutual interference on the active components. They are easily adaptable to models of standard airplanes, airships, etc., and have, in general, an axis of symmetry such that the aerodynamic moment exerted on them by the air flow is practically nil with respect to the axis about which the moments are measured. No correction of the measured moment is therefore required. Some details regarding the different fittings are given below.

a) Pitching moments.- For pitching-moment measurements the

plate is controlled by a three-pronged steel fork of adjustable width (Fig. 10). The three prongs are slightly tapered and have a mean diameter of 3.5 mm (0.14 in.) at their tips. The flat-sided slide-type support permits of varying the axial distance between the lateral prongs from 20 to 60 mm (0.8 to 2.4 in.), while continually keeping their tips in the same horizontal line with that of the central prong. An axial distance of 50 mm (2 in.) is adopted in the current tests. This is great enough to define clearly the direction of the three points, which direction is finally marked on the calibrated plate.

Two plates normal to the wing, each with three 3.5 mm (0.14 in.) holes (Fig. 11), are provided at the wing tips of the model. The prongs of the fork engage in the holes and thus support the model. The plates should be mounted in such a manner that the straight line connecting their central holes would be normal to the plane of symmetry of the model and pass through the point corresponding to the C.G. of the airplane. The line passing through the centers of the three holes of each plate should preferably be parallel to the direction of flight. The plate arrangements are shown in Figures 12a-12c.

Note.- In the case of parasol airplanes, in which the C.G. is located far below the wing, the wing-tip fittings may become extremely important. In this case, low attachment fittings might be used and the measured moments corrected by calculation. This correction is very small when the pivoting center is on

the normal to the flight axis passing through the C.G. of the airplane, because it applies only to the total-drag component parallel to this axis.

b) Yawing moments.- The two types of attachment fittings shown in Figure 13 were designed for measurements of yawing moments. In the left-hand fitting, which is used for small models, the spindle B, which controls the plate indicating the angle of attack, is connected with the model by a small steel spindle. A small circular plate of 40 mm (1.6 in.) diameter is secured by four wood screws to the bottom of the fuselage and hinged to the upper end of the spindle. The centering of the disk is insured by a small pin of 5 mm (0.2 in.) diameter and 10 mm (0.4 in.) length. The small disk is hinged in such a way as to allow some liberty in the choice of the pivoting axis with respect to the airplane, in order to enable the correct installation of the latter and the measurement of the moments with respect to an axis always perpendicular to the wind.

This support requires no attachment device on the model excepting a hole, 5 mm in diameter and 10 mm deep, in the fuselage vertically in line with the point corresponding to the C.G. of the airplane. The surface of the fuselage must be fitted to the disk around this hole within a circle of 40 mm (1.6 in.) diameter.

Figure 14 shows the above-described attachment fitted to the bottom of a fuselage. Another type of support, shown on the

right in Figure 13, is made for heavy models. The model is attached to two small plates 10 cm (about 4 inches) apart on a U-shaped support. One of the vertical arms of the U is movable, thus making it possible to vary the position of the axis of rotation with respect to the airplane. The two vertical arms of the U being equal, the aerodynamic moment about the axis of rotation of the wind vane is always practically zero. Still another support of the same type, but with arms 15 cm (about 6 in.) apart, was made for testing airship models.

c) Rolling moments.- The attachment fitting for rolling-moment measurements has no peculiar features, being developed along the general lines and based on the same principle as the fitting shown in Figure 14.

Aerodynamic effect of the supports.- It may be questioned as to whether the supports shown in Figures 12a and 12c may not appreciably affect the air flow about the models. This question was investigated in the two following tests conducted in the small wind tunnel at Issy-les-Moulineaux:

1. An airfoil 80 x 16 cm (29.5 x 6.3 in.) was mounted on the wire balance of the wind tunnel. The polar was first determined with the airfoil alone in the air flow and then with it subjected to the influence of large plates held near its marginal edges only a few millimeters from the surface by long, rigid rods. The plates were thus held, in turn, near the lower and upper surface of the airfoil without causing the polars to dif-

fer materially.

2. The moments about the leading edge of the isolated airfoil were determined both by the balance and by the wind-vane methods. As it is difficult to make an airfoil, when mounted like a wind vane, pivot exactly about the leading edge, the moments about two axes, 8 and 16 cm (3 and 6 in.) aft of the leading edge were determined successively. The moments about the leading edge can be easily deduced from the two moment curves thus obtained. The results are compared in Figure 15 with those obtained directly by balance measurements.

The measurements obtained by these two methods agree perfectly well. The last comparison is particularly interesting, because the balancing of large airfoil moments required very large plates P to be mounted on the transverse spindle a b, of the wind vane (Fig. 1). These plates reached dimensions of 10 × 10 cm (4 × 4 in.) and even 15 × 15 cm (6 × 6 in.). According to Figure 15, the aerodynamic interference between these plates and the airfoil is practically nil.

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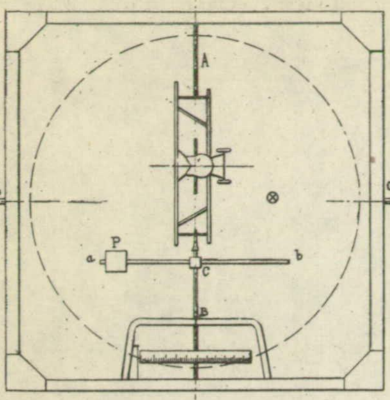
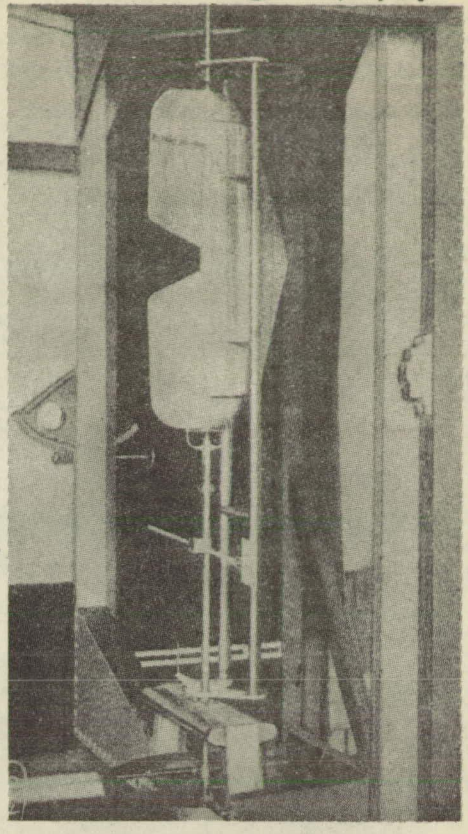


Paris Office Fig.1 N.A.C.A.

Fig.1 Mounting of model for measuring pitching moments.



Taken from "Bulletin Technique" No. 66 Feb. 1930

Fig.4 Mounting of horizontal tail surfaces for measuring hinge moments.

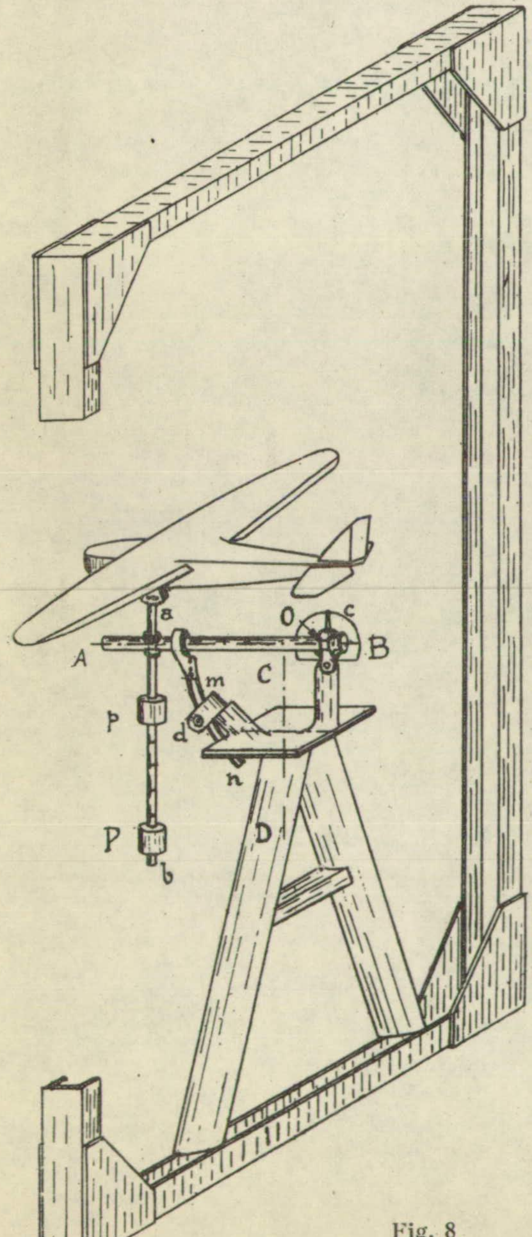
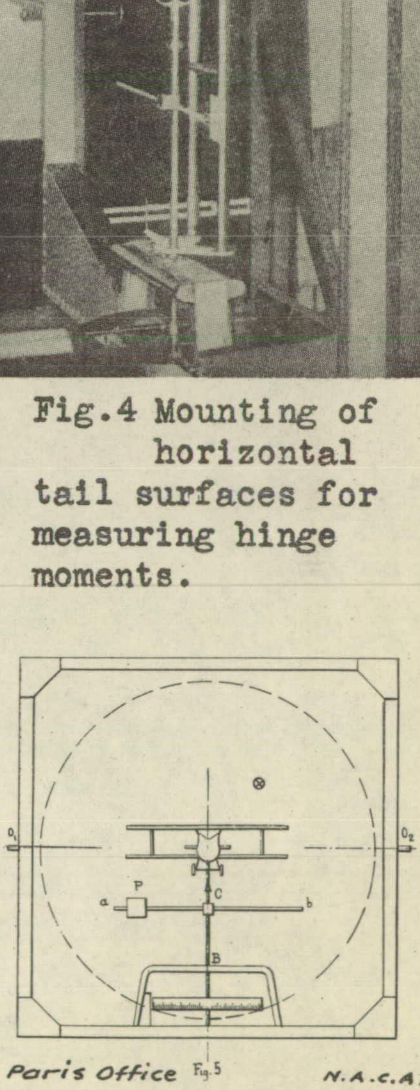


Fig. 8

Fig.8 Mounting of model for measuring rolling moments.



Paris Office Fig.5 N.A.C.A.

Fig.5 Mounting of model for measuring yawing moments.

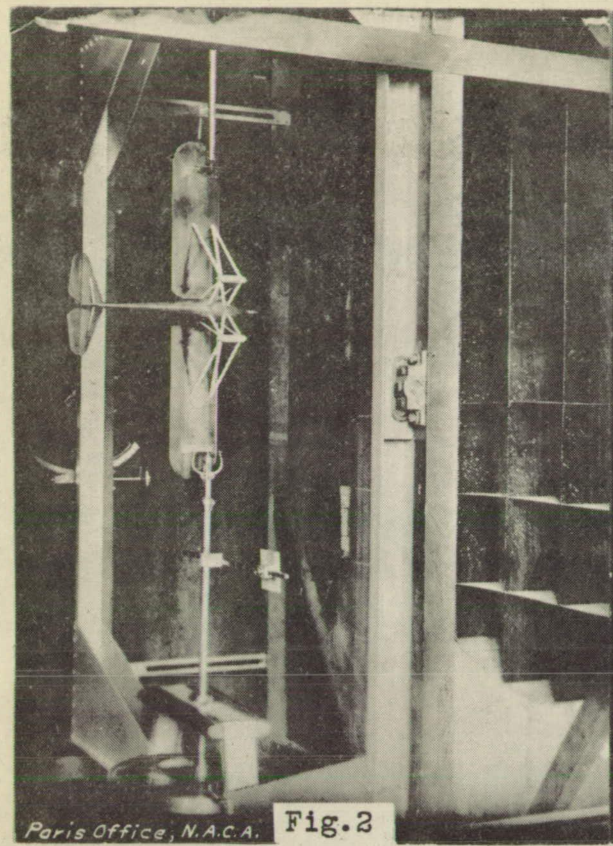


Fig.2

Fig.3

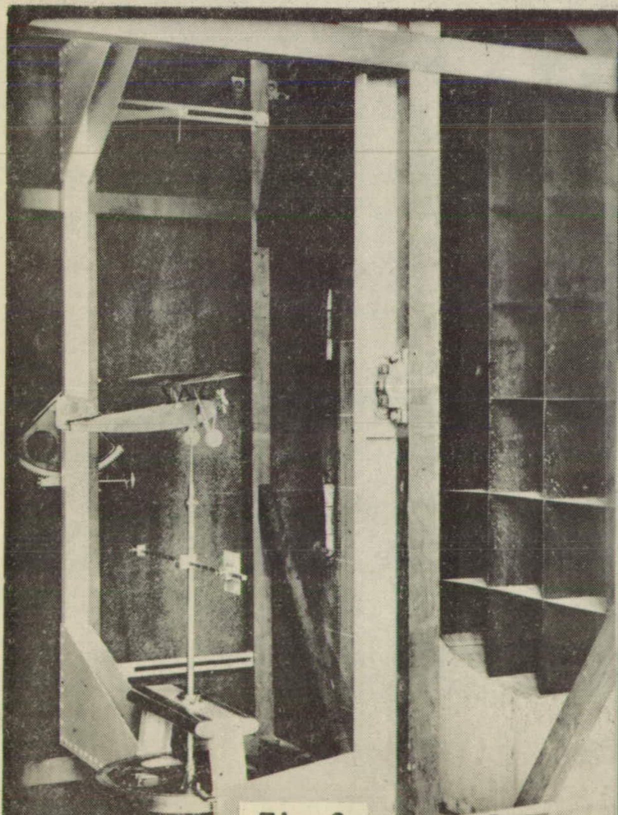


Fig.6

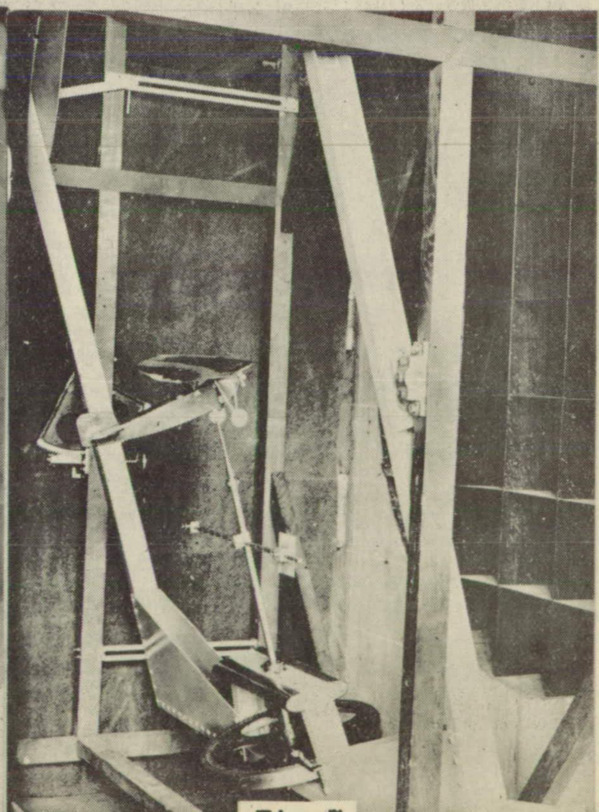


Fig.7

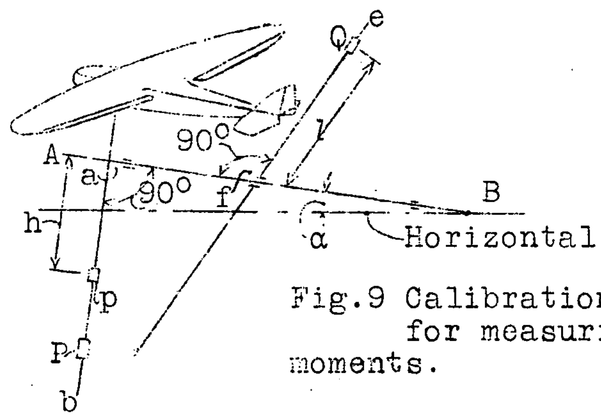


Fig.9 Calibration of device for measuring rolling moments.

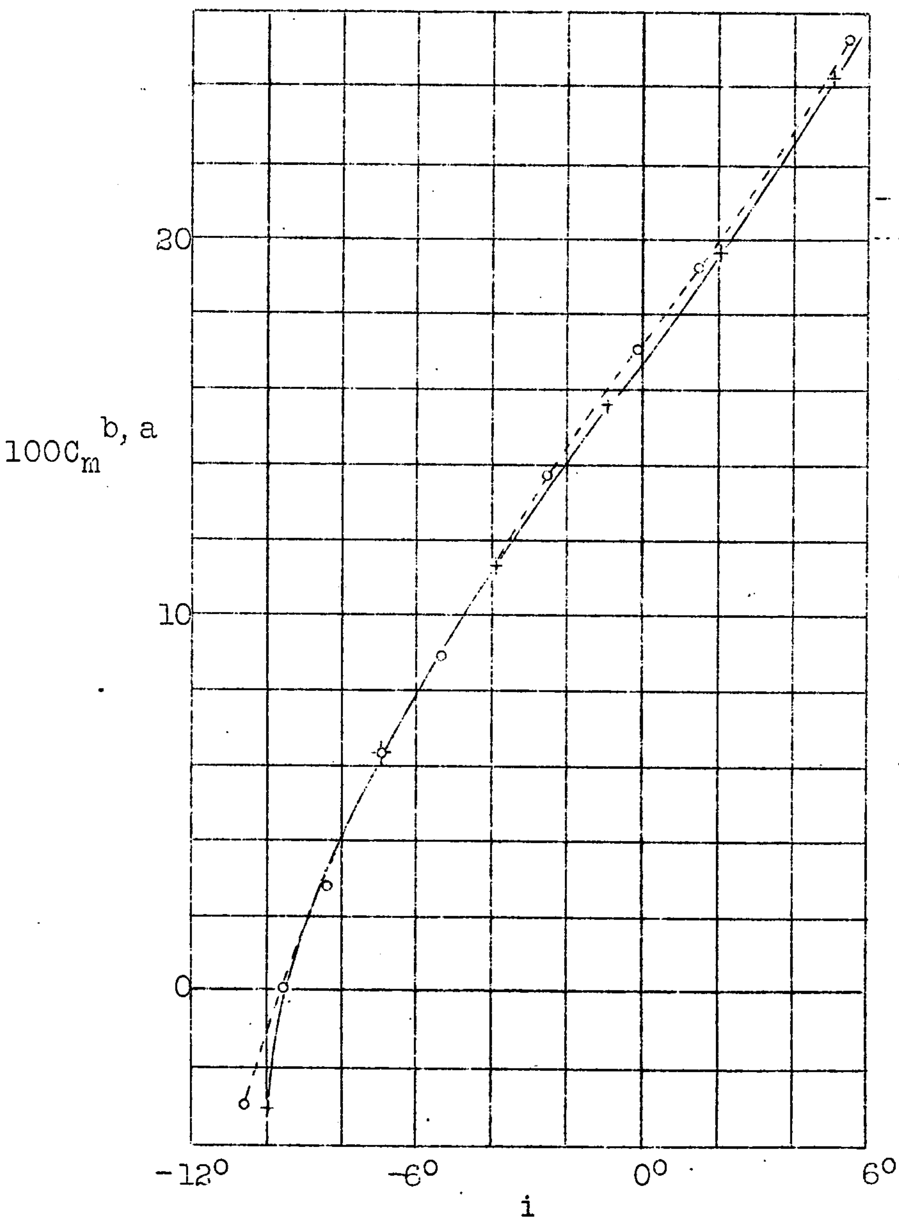


Fig.15

Comparative curves for the moments of a wing with respect to the leading edge, as obtained by the wind-vane and the balance methods.

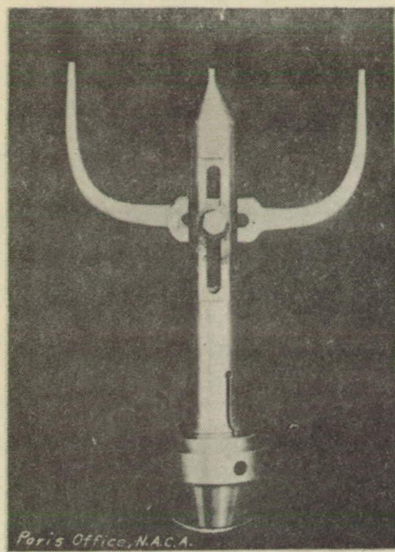


Fig.10 Three-pronged adjustable fork controlling the plate of the installation for measuring pitching moments.

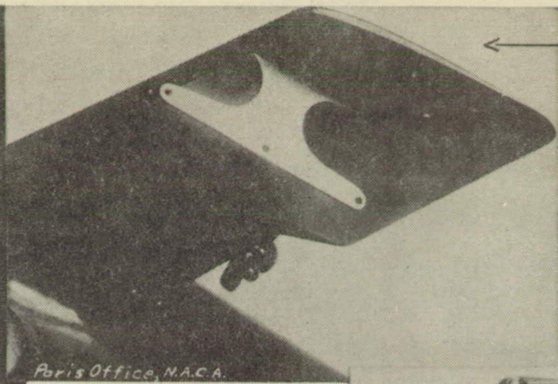


Fig.11 Plate normal to airplane wing, with the three holes for receiving the prongs.

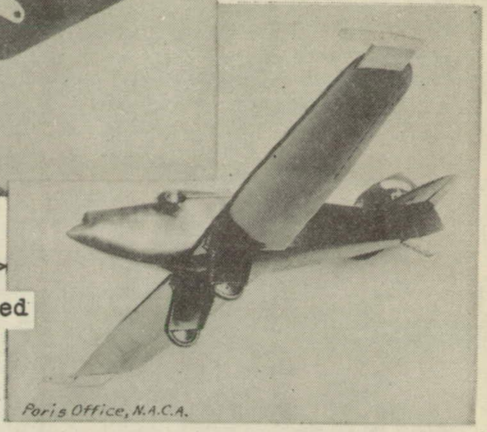


Fig.12c Plates mounted at the wing tips of a low-wing monoplane.

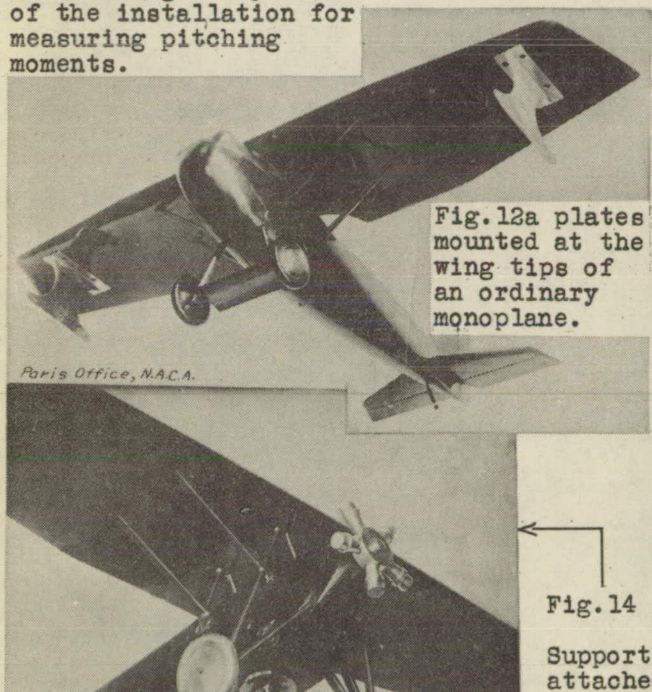


Fig.12a plates mounted at the wing tips of an ordinary monoplane.

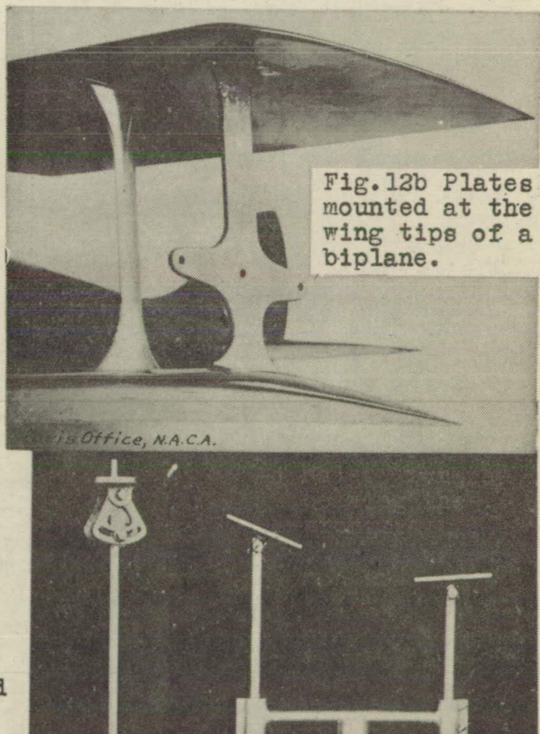


Fig.12b Plates mounted at the wing tips of a biplane.

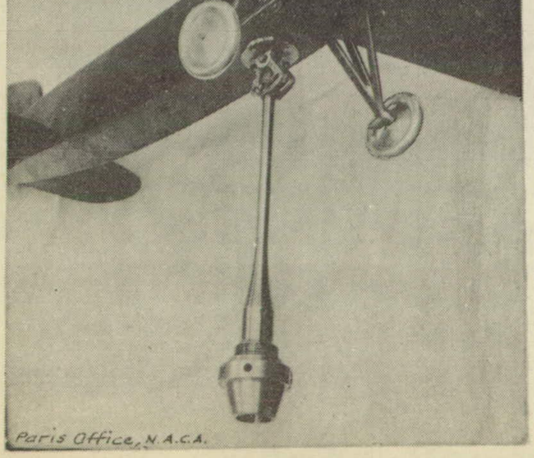


Fig.14

Support attached to the bottom of a fuselage for measuring yawing moments.

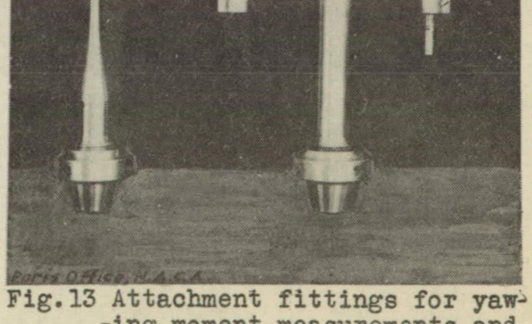


Fig.13 Attachment fittings for yawing moment measurements and directional-stability tests.